Physiological and Physicochemical Responses of ‘Sai Nam Phueng’ Tangerine to Commercial Coatings

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Abstract. Tangerine fruit cv. Sai Nam Phueng was coated with six commercial coatings: Citrashine, Fomesa, Citrosol AK, Supershine-C, Zivdar, and Perfect Shine. Fruit were coated using gloved hands and stored at room temperature (23 ± 3 °C) and 56% ± 5% relative humidity. Physiological and chemical properties were recorded on Days 0, 1, 4, 7, 10, and 13. All coated fruit had lower respiration rates, reduced weight loss, higher gloss, and better appearance than control fruit. Coatings somewhat increased total soluble solids levels, but had no major effects on pH, titratable acidity, or vitamin C contents. Among the various wax formulations, tangerines coated with Zivdar, and to a lesser extent Perfect Shine, had the highest internal O2 and lowest internal CO2 levels, resulting in the lowest juice ethanol levels. Application of other coatings, especially Citrosol AK and Supershine-C, resulted in enhanced accumulation of off-flavors and decreased sensory acceptability.

Tangerine (Citrus reticulata Blanco) is a subtropical fruit of high commercial value in the fruit market and is commonly consumed as a fresh fruit in Thailand. In commercial practice, tangerine fruit are coated to increase shine and reduce water loss. Many imported coatings are being used by various packing-houses in Thailand. Surface coatings can improve the postharvest quality of horticultural commodities (Hagenmaier and Baker, 1995). A principal disadvantage of coatings is the development of off-flavor, which can be adversely affected by the coating for reasons related to permeation of gases through the peel (Hagenmaier, 2002; Hagenmaier and Baker, 1993). If anaerobic conditions occur, an excessive build-up of volatile compounds such as acetaldehyde and ethanol in citrus fruit can lead to the production of off-flavor (Chen and Baldwin, 2000). As a result, coatings sometimes have been used to improve the postharvest quality of horticultural produce, which are usually used by packing-houses (Table 1) and non-coated fruit were used as controls. Coatings were applied using a scale of 1 to 4 in which 4 = excellent, 3 = slightly off-flavor, 2 = moderately off-flavor, and 1 = extremely off-flavor. Fruit taste was rated “unacceptable” when the score was below 3.

Visual appearance. Tangerine fruit were rated for visual quality, wilting, and shriveling using a scale of 1 to 5 in which 5 = excellent, 4 = good, 3 = fair, 2 = poor, and 1 = unusable. Fruit appearance was rated “unacceptable” when the score was below 3.

Determination of internal O2 and CO2. Ten fruit were used per treatment for each coating. The internal gas was withdrawn by a syringe (previously flushed with helium gas to remove oxygen) with the needle inserted through the blossom end into the internal space of fruit submerged in water (Hagenmaier, 2001). The O2 and CO2 concentrations were measured with a gas chromatograph (Model GC-8A; SHIMADZU, Tokyo, Japan) equipped with a thermal conductivity detector fitted with a CTR-1 column (2 m × 6 mm o.d.) (Alltech, Deerfield, IL) consisting of an outer column (Parapak Type N; 80-100 Mesh; SHIMADZU). The column temperature was 65 °C and the thermal conductivity detector was 110 °C. Peak areas obtained from standard gas mixtures were determined before and after analysis of samples. Oxygen concentration was calculated from the O2-Ar peak area after correction for 0.9% Ar in atmosphere (Hagenmaier, 2001). Ethanol concentration was determined using an ethanol assay kit (Diagnostic Chemical Limited, Charlottetown, Canada) as described by Bontinckens and Theorell (1951). The pooled juice of 10 fruit was extracted using a juicer maker. Ten microliters of juice was mixed with 1.5 mL of buffer-NAD-ADH-buffer mixture and incubated for 20 min at 25 ± 2 °C. The absorbance was measured at 340 nm within 30 min. The concentration of ethanol was calculated from a graph made from standard ethanol solutions. Ethanol was measured in triplicate determinations.

Respiration rate. Respirations rates were measured every 3 d and eight fruit (≈1 kg)
were sealed in a plastic chamber (17.5 cm × 27.0 cm × 11.5 cm) with continuous air flow at 23 ± 3 °C. A 1-mL gas sample was withdrawn with a plastic-tight syringe and analyzed for CO2 by gas chromatograph (Model GC-8A; SHIMADZU) fitted with a Parapak Type N (80–100 Mesh; SHIMADZU) consisting of an outer column (CTR-1 column; 2 m × 6 mm o.d.; Alltech). The column temperature was 65 °C and the thermal conductivity detector was 110 °C. The respiration rate was expressed as milligrams of CO2 per kilogram of fruit per hour (mg CO2/kg/hr).

Measurement of total soluble solids (TSS), titratable acidity (TA), pH, TSS/TA ratio, and ascorbic acid. Three fruit of three replications per treatment were squeezed with a hand-press juicer. The juice was measured for total soluble solids content with a digital refractometer (Model PR-101; ATAGO, Tokyo, Japan). The pH of juice was measured by a pH meter (Model CG 842/14 pH; SCOTT, Hofheim, Germany). Titratable acidity (TA) was determined by diluting 10 mL of fruit juice to 100 mL with distilled water and titrated with 0.1 N NaOH to a pH 8.2. TA was expressed as percent citric acid per 100 mL fruit juice. The ratios of total soluble solids (TSS) to TA were calculated as the average of the ratios. Ascorbic acid content was determined by the 2,6-dichloroindophenol titrimetric method (Ranganna, 1986). The results were expressed in milligrams of ascorbic acid per 100 mL fruit juice.

Statistical analysis. One-way analysis of variance was used to determine treatment effects and comparisons were made at P ≤ 0.05 using the least significant difference test to separate means (SPSS software; SPSS Inc., Chicago, IL).

Results and Discussion

Weight loss. The weight loss of commercially coated fruit was significantly less than that of the control fruit. The least weight loss was exhibited by the Fomesa coating followed by Citrashine, Supershine-C, Zivdar, Citrosol AK, and Perfect Shine (Fig. 1). Weight loss is mainly caused by fruit transpiration in which water moves out of the fruit by vapor phase diffusion driven by a gradient of water vapor pressure between inside and outside of the fruit. The reduction in weight loss was probably the result of the effects of these coatings as a semipermeable barrier against O2, CO2, moisture, and solute movement, thereby reducing respiration, water loss, and oxidation rates (Baldwin et al., 1999). The rate of water loss can be reduced by 30% to 50% with the use of some waxes (Wills et al., 1998). Carnauba wax and shellac are good barriers of moisture loss, whereas polyethylene have higher permeability of water vapor (Hagenmaier and Baker, 1993; Hagenmaier and Shaw, 1992). Similar results were obtained with Sazuma mandarins and Shamoji oranges. The data show that the lowest weight loss was manifested in Primafresh-coated fruit, whereas the highest weight loss was recorded for the control fruit followed by fruit coated with Britex, PacRite-StorRite, Decco, and Natural Zivdar coatings (Mannheim and Soiffer, 1996).

Gloss. Coated ‘Sai Nam Phueng’ tangerines had higher initial gloss than non-coated fruit (Fig. 2) as previously reported for ‘Mor’ mandarins (Porat et al., 2005). Tangerines coated with Citrashine and Perfect Shine had the highest gloss unit (Fig. 2). The high-gloss coatings were composed mainly of shellac and wood rosin more than coatings made from waxes such as polyethylene or carnauba wax (Hagenmaier and Baker, 1994). By observation with the naked eye, the gloss of all coatings decreased during storage but remained higher than the uncoated fruit. Decrease of gloss during storage did not depend on coating thickness (Hagenmaier and Baker, 1994).

Estimation of off-flavor. The flavor scores of coated tangerine fruit were evaluated after storage for 7 d. The flavor was perceived as more “fermented” for fruit coated with Supershine-C, Citrosol AK, Citrashine, and Fomesa than for fruit coated with Zivdar and non-coated control fruit (Fig. 3). Flavor can be adversely affected by the coating that reduces permeation of gases through the peel. Citrus fruit, like other plant products in general, continues to respire after harvest, intake O2, and release CO2. Unless these gases are able to pass through the peel without too much restriction, the CO2 concentration builds up in the fruit and the O2 becomes depleted. These changes can result in a change in the respiratory process so that off-flavor is produced (Hagenmaier, 1998). Extremely low O2 levels or excessively high CO2 levels that induce fermentation can result in the generation of off-flavor (Cohen et al., 1990). There was a relationship between the amounts of ethanol content and low O2 and high CO2 concentrations in tangerine fruit. The fruit coatings apparently reduced passage of O2 through the peel and thus created partial anaerobic conditions in the fruit, which resulted in the formation of products of anaerobic respiration, e.g., ethanol and acetaldehyde. The coatings also prevented the exit of CO2, ethanol, and acetaldehyde from the fruit, which led to fermentation and off-flavor induction (Cohen et al., 1990; Mannheim and Soiffer, 1996). Baldwin et al. (1995) reported marked increases in flavor volatiles, especially ethanol.

Table 1. Commercial coatings, main components, and their sources.

<table>
<thead>
<tr>
<th>Name of commercial coating</th>
<th>Abbreviation</th>
<th>Main components</th>
<th>Source of product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citrashine</td>
<td>CIS</td>
<td>Shellac-based wax formulated with purified natural secretion and water-emulsifying agents</td>
<td>Citrashine (Pty) Ltd., South Africa</td>
</tr>
<tr>
<td>Fomesa (Waterwax)</td>
<td>FOM</td>
<td>10% oxidized polyethylene wax</td>
<td>Fomesa Fruitech, S.L., Spain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8% glycerol ester of wood rosin</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2% ammonium hydroxide</td>
<td></td>
</tr>
<tr>
<td>Citrosol AK</td>
<td>CSA</td>
<td>18% w/v carnauba and rosin</td>
<td>Productos Citrosol, S.A., Spain</td>
</tr>
<tr>
<td>Supershine-C</td>
<td>SUS</td>
<td>18% w/v waxes, modified gum, rosin, oxidized polyethylene, and adjuvants</td>
<td>Tecnix, Spain</td>
</tr>
<tr>
<td>Zivdar</td>
<td>ZIV</td>
<td>18% w/v waxes, shellac, polyethylene wax, and imazalil</td>
<td>Safepack Products Ltd., Israel</td>
</tr>
<tr>
<td>Perfect Shine</td>
<td>PFS</td>
<td>Carnauba wax, natural resin, fatty acid, fatty alcohol, ammonia</td>
<td>P.S. Wax Tech, Co. Ltd., Thailand</td>
</tr>
</tbody>
</table>

*CComponents were declared on the product labels.
CO2 and low O2. This can benefit fruit shelf life with low permeability offer more of a barrier to gas exchange between the fruit and external atmosphere (Ke and Kader, 1990).

Visual appearance. Tangerine fruit coated with commercial coatings showed better visual appearance results as compared with the non-coated control fruit. An appearance is the most important quality attribute of fresh produce with primary concern for size and color, uniformity, glossiness, and absence of defects in shape (Aked, 2000). Appearance can be affected by surface dehydration resulting in whitening, waxiness, and discoloration (like resulting from enzymatic browning). Selective coating materials can reduce moisture loss, control surface dehydration and discoloration, delay the surface whitening, and enhance the glossiness of fruit surfaces (Lin and Zhao, 2007). Data regarding storage intervals showed a gradual decline in appearance over the storage period prolonged (data not shown). This may be the result of the loss of moisture, which in turn affected the quality of fruit. Water loss can cause shrinkage, softening of the flesh, ripening, senescence through ethylene production, and other metabolic changes (Bai et al., 2002).

Internal O2 and CO2. Uncoated fruit had lower internal O2 whereas it had 2% higher CO2 than atmosphere. In contrast, coated fruit had internal O2 lower by 9% to 16% and internal CO2 concentrations higher by 3% to 15% (Fig. 4). Gas exchange between internal fruit and external atmosphere is by permeation through the cuticle and by diffusion through pores. Application of surface coatings covers the cuticle and may block pores on the fruit surface (Ben-Yehoshua et al., 1985; Hagenmaier, 2000). Coatings with low permeability offer more of a barrier to gas exchange between the fruit and external atmosphere, resulting in a modified internal fruit atmosphere of relatively high CO2 and low O2. This can benefit fruit shelf life in the same way as controlled atmosphere or modified atmosphere packaging does, whereas excessive modification can cause anaerobic metabolism (Hagenmaier, 2002). Furthermore, internal gas composition was highly dependent on coating type and thickness. In previous works, the effects of different types of wax on gas permeability and anaerobic conditions were studied in various orange and mandarin varieties. It was concluded that wax-based coatings, especially for polyethylene-based, are much more permeable than carnauba-, shellac-, and wood rosin-based coatings and are more suitable for coating mandarins (Hagenmaier, 2000; Hagenmaier and Baker, 1993, 1995; Hagenmaier and Shaw, 1992; Manhein and Soffer, 1996). Hagenmaier and Shaw (1991, 1992) measured gas exchanges for many commercial fruit coatings. It was found that resin-based coatings (shellac or wood rosin) were less permeable to O2, CO2, and ethylene than carnauba and other wax-based coatings. Furthermore, the internal CO2 of grapefruit and ‘Valencia’ orange was lower for polyethylene- and carnauba-based coatings than for shellac and resin (Hagenmaier and Baker, 1994).

Determination of ethanol content. Ethanol content of the juice from coated fruit varied considerably for each coating treatment and increased during storage. Non-coated fruit showed the lowest ethanol content. The highest ethanol content occurred in fruit with the Fomesa, Citrosol AK, and Supershine-C coatings. The Perfect Shine and Zivdar coatings gave a relatively lower ethanol content than other coatings (Fig. 5). The coatings that are applied to fruit form barriers to the passage of O2 and CO2 through the fruit peel (Hagenmaier, 2005). Low O2 and/or high CO2 can induce anaerobic respiration and enhance fermentation (Matthesis et al., 1991). Ethanol content in the coating application was notably higher as a result of the amount of rosin (shellac or wood rosin) formulations than that of wax (polyethylene- or carnauba-based) coatings and control fruit. With a lower permeability...
to gases, shellac and wood resin coatings result in the oxidation of internal O₂ and higher internal CO₂, and a subsequent build-up of acetaldehyde and ethanol under anaerobic conditions, which leads to off-flavor in citrus fruit (Baldwin et al., 1995; Cohen et al., 1990; Hagenmaier, 2000, 2002; Hagenmaier and Baker, 1993). Ahmad and Khan (1987) found significant amounts of ethanol in waxed mandarins accompanied with a change in flavor. These researchers attributed the off-flavor to an insufficient supply of O₂ through the wax coating, which caused partial anaerobic respiration. Similar results were reported for wax-coated ‘Pineapple’ oranges (Nisperos-Carriedo et al., 1990).

**Respiration rate.** Statistical analysis showed a significant difference between control and coated samples for respiration rates.

The control fruit had a higher respiration rate than coated tangerine fruit. Supershine-C coating provided the lowest respiration rate compared with others. The production of CO₂ for the coated fruit was lower than in the control (Fig. 6). The suppression of respiration was likely the result of the modification of the internal atmosphere of the fruit (decreasing O₂ and increasing CO₂) caused by the semipermeable characteristics of the coatings to these gases (Banks, 1984).

Reduction of the respiration rate as a result of coatings has also been reported for cherries (Martinez-Romero et al., 2006), strawberry (El Ghaouth et al., 1991), and longan (Jiang and Li, 2001).

**Measurement of total soluble solids (TSS), titratable acidity (TA), pH, TSS/TA ratio, and ascorbic acid.** Comparison of treatment means ± SD on Day 7 (Table 2) showed that %TSS found in tangerine treated with Zivdar was higher than Citrashine, Fomesa, and untreated fruit. However, no significant difference of %TSS was found in tangerine fruit coated with Citrosol AK, Supershine-C, or Perfect Shine coatings. Coated fruit showed less TSS loss than control fruit and had also been reported for mandarin coated with different emulsions (Togrul and Arslan, 2004).

The pH value in fruit coated with Zivdar (3.53 ± 0.04) was higher than Citrashine (Table 2). There were no significant differences in pH between fruit treated with Zivdar, Fomesa, Citrosol AK, Supershine-C, and Perfect Shine coatings and the non-coated control. Comparison of treatment means showed an increasing trend of pH in all treatments during storage for 13 d (data not shown). The increase in pH may have been the result of the metabolisms of acids with respiration during storage (Togrul and Arslan, 2004).

Coating with Citrashine resulted in the highest %TA (0.59 ± 0.04), whereas the lowest %TA (0.44% ± 0.07% and 0.45% ± 0.04%) were observed in Zivdar- and Perfect Shine-coated fruit (Table 2). There was a decrease in acidity in all treatments during storage (data not shown). In this investigation, coating treatments did not affect loss of TA in tangerine fruit during storage.

The TSS/TA ratio of tangerine coated with Zivdar was higher than that of tangerines coated with Citrashine, Fomesa, Supershine-C, and non-coated control fruit (Table 2). Moreover, the results showed that the TSS/TA ratio of all treatments was increased during storage (data not shown). Similar results were found in Aloe vera-coated cherry and starch-coated strawberry (Malik and Grossmann, 2003; Martinez-Romero et al., 2006).

The ascorbic acid content of coated tangerine fruit compared with non-coated control was not significantly different after 7 d of storage (Table 2). Ascorbic acid of yellow passion fruit coated with Fruit wax, Sparitrus, Sunny Side Citrus, and polyethylene was not significantly different from control fruit (Mota et al., 2003).

**Conclusion**

Zivdar and Perfect Shine wax are best suited for coating ‘Sai Nam Phueng’ tangerine

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**Table 2.** The quality attributes of ‘Sai Nam Phueng’ tangerine fruit stored at ambient temperature (23 ± 3 °C) and 56% ± 5% relative humidity for 7 d with wax treatments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>TSS (%)</th>
<th>pH</th>
<th>TA (%)</th>
<th>TSS/TA</th>
<th>Vitamin C (mg/100 mL juice)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>11.70 ± 0.98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.23 ± 0.19&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.59 ± 0.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19.85 ± 1.68&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.02 ± 1.91</td>
</tr>
<tr>
<td>FOM</td>
<td>11.37 ± 0.60&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.36 ± 0.02&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.53 ± 0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.86 ± 3.91&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.66 ± 1.10</td>
</tr>
<tr>
<td>CSA</td>
<td>11.30 ± 0.44&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.45 ± 0.17&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.48 ± 0.10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>24.05 ± 4.69&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20.38 ± 2.21</td>
</tr>
<tr>
<td>SUS</td>
<td>10.80 ± 1.21&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.39 ± 0.10&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.50 ± 0.07&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.89 ± 3.53&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.86 ± 1.10</td>
</tr>
<tr>
<td>ZIV</td>
<td>12.17 ± 1.00&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.53 ± 0.04&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.44 ± 0.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>28.45 ± 6.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.75 ± 1.10</td>
</tr>
<tr>
<td>PFS</td>
<td>11.13 ± 0.32&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.45 ± 0.01&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.45 ± 0.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>24.94 ± 1.70&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20.38 ± 1.10</td>
</tr>
<tr>
<td>Non-coated</td>
<td>9.90 ± 0.70&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.49 ± 0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.48 ± 0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20.85 ± 2.47&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19.11 ± 0.00</td>
</tr>
</tbody>
</table>

Values are means ± SD of three measurements. Mean separation within columns by the least significant difference test at P ≤ 0.05.

Means followed by different superscript letters within a column are significantly different.

TSS = total soluble solids; TA = titratable acidity; LSD = least significant difference.
fruit because they had the least effects on modification of internal gas atmosphere, ethanol accumulation, and development of off-flavor. All coatings reduced respiration rates and weight loss and provided higher gloss and better appearance than control fruit. Some coatings increased TSS levels but no major effects on pH, TA, and vitamin C contents.

Literature Cited


